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Cognizance in cognitive development: A longitudinal study

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ABSTRACT

This study explored longitudinally how cognizance mediates between executive and reasoning process from 4 to 10 years of age. Four-, 6-, and 8-years old children were tested twice by executive (inhibition, flexibility in shifting, and working memory), cognizance (awareness of perceptual and inferential origins of knowledge, first- and second-order ToM, and awareness of similarities and differences between cognitive processes), and reasoning tasks (deductive and Raven-like fluid reasoning tasks). Perceptual awareness, first-order ToM, and simple inductive and deductive reasoning were acquired at preschool; inferential awareness, awareness of cognitive processes, and relational and deductive reasoning were mastered later in childhood. The various processes preserved their relative functional autonomy; however, there were two factors standing for their interactions: one for the state of ability at a time and one for general change dynamics. Latent change score modeling and latent transition analysis showed that cognizance was the best proxy of the general change factor collecting reasoning and executive influences early and leading transitions to higher level reasoning later. Implications for developmental, psychometric, and developmental psychopathology theories are discussed.

1. Introduction

Cognizance is awareness of cognitive processes. Here it is operationalized as (1) awareness of the role of perception and inference in knowledge and problem solving; (2) awareness of procedural characteristics and demands of mental processes; and (3) theory of mind. This study explored the development of these process from 4 to 10 years and their mediation between executive and reasoning processes. Specifically, we examined how each of these cognizance processes interacts with executive and reasoning processes contributing to the transformation of changes in executive possibilities into changes in inductive and deductive reasoning. Below we first review research on the relations between these processes and then focus on changes in these relations with development. Our aim is to highlight possible patterns of relations during pre- and primary school period of development yielding predictions to be tested by this study.

1.1. Relations among executive, cognizance, and reasoning processes

Since the 60 s, the study of mental awareness developed along two related but distinct lines of inquiry: (i) metacognition, i.e.,

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knowing about knowing and awareness of cognitive processes involved in knowing (e.g., Beran, Brandl, Perner, & Proust, 2012; Efklides, 2001; Flavell, 1979; Pillow, 2008) and (ii) Theory of Mind (ToM), i.e., awareness about other person's mental states (e.g., Perner, 1993; Wellman, 2014). In recent years a new strand of research, executive processes, came into focus. These include attention control, flexibility in shifting between representations, and working memory; altogether, they allow deliberate adjustment of one's thoughts or actions in sake of cognitive or behavioral goals (Chevalier, Martis, Curran, & Munakata, 2015; Diamond, 2013; Zelazo, 2015). Many studies explored relations between mental awareness and executive processes; they all concur that they are related. However, the nature of their relations is unclear.

Several studies showed that executive control is necessary but not sufficient for awareness of one's own mind or others' mental states (ToM). Specifically, several longitudinal studies showed that the state of executive functions, such as attention control and inhibition at 2–3 years predicted the state of ToM one year later (Carlson, Madell, & Williams, 2004; Sabbagh, Xu, Carlson, Moses, & Lee, 2006). Along the same line, other studies showed that working memory predicted (Lecee, Bianco, Devine, & Hughes, 2017) or caused changes in ToM in 9–10 years old children (Lecee & Bianco, 2018). However, other studies suggested mutual relations, such that ToM facilitates flexibility in shifting between rules, executive control facilitates ToM, and both draw on conditional reasoning (Kloo & Perner, 2008; Perner & Lang, 1999).

The evidence about the relations between awareness of one's own (metacognition) and of other's mental states (ToM) is also inconsistent. On the one hand, Carruthers (2009) claimed that metacognition results from turning our mindreading capacities, the core tool of ToM, upon ourselves. Schneider (2008) suggested that ToM facilitates metacognitive awareness because it yields insight into inferential and interpretative processes by inviting attention to the mental states of others in contrast to one's own mental states. This insight facilitates reasoning and problem-solving development in different domains. On the other hand, others claimed that metacognition is the basis for ToM. Bradford, Jentzsch, and Gomez (2015) showed that processing beliefs about oneself is faster than processing beliefs about others, implying that 'self' is the stem of understanding the 'other', placing less demands on mental processing. Finally, Wellman, Cross, and Watson (2001), based on the meta-analysis of a large number of studies, found that there are few, if any, differences between understanding one's own and others' false beliefs.

Perhaps the contradiction is apparent rather than real, indicating the operation of a common mental core. Demetriou, Makris, Kazi, Spanoudis, and Shayer (2018) proposed that, minimally, this is awareness *of developmentally current representations, including a goal and goal relevant representations.* This allows the construction of *goal relevant* executive plans underlying action sequences, where inhibitions and activations are arranged according to their goal relevance; thus, shifting between them revolves as a function of diminishing distance from the goal. Minimally, in Stroop-like inhibition tasks, it is enough to be aware of the goal and the goal-response mapping: naming ink-color or inverting meaning saying night for sun and day for moon. In shifting tasks, this awareness involves at least two rules (e.g., sort by color or by shape) and the higher-order sorting choice rule so that a shifting occurs when this rule appears. In working memory, it involves the executive goal and some stimuli to recall. In ToM tasks, it includes one's own representations of a situation (e.g., object transferred from Box A to Box B), the other person's representation (i.e., s/he saw object placed in Box A but not transfer to Box B), and an epistemic rule that one's knowledge is constrained by one's information about the situation, perceived or inferred. Reasoning requires awareness of gaps in information (yielding a reasoning goal) and awareness of the representations to be integrated by inference which are to be focused on in succession. This awareness includes the representations associated with the premises involved, possibly remembered relevant episodes, and awareness of epistemic rules related to truth and/or validity of relations allowed between premises. Thus, a minimum level of awareness is part of psychometric g, together with attention control, shifting, working memory, and inference (Demetriou & Kazi, 2006; Demetriou, Makris, Kazi, Spanoudis, Shayer, & Kazali, 2018; Makris, Tachmatizdis, Demetriou, & Spanoudis, 2017). At the behavioral level, this awareness may be associated with executive processes allowing focusing and refocusing mental processes or skills needed to perform the task at hand, such as revisiting information represented and shifting between representations. For instance, Agostino, Johnson, and Pascual-Leone (2010) found that updating, an executive function, mediates between age or mental capacity (i.e., mental attention and working memory) and mathematical cognition, from 8 to 13 years of age. This awareness may be an integral part of psychometric general intelligence (g). Indeed, Coyle, Elpers, Gonzalez, Freeman, and Baggio (2018) showed recently that a latent ToM factor standing for performance on ToM tasks correlated strongly with psychometric g, leaving no room for relations between specific cognitive processes and specific aspects of ToM.

Reflection is the active aspect of cognizance. In Piaget (2001) theory, reflective abstraction, i.e., focusing on representations, relating them, and abstracting and projecting their similarities on a higher level, is the engine of equilibration, the driving mechanism of cognitive development. Zelazo (2004) Levels of Consciousness (LOC) model postulates that self-reflection is *the* central process interlinking other processes thereby generating awareness about them. This process drives cognitive development because higher LOC emerge from conscious reflection on the relations between representations at a particular level of awareness generating representations at a higher level of awareness. Zelazo (2015) argued that these changes in awareness underlie changes in executive control and metacognition, because they alter the resolution of processes one can focus on and process.

Over childhood, children build increasingly more refined representations of available control modes and potential alternatives. As a result, they can better evaluate adequacy and relevance between task demands and available control means. In line with this model, Allen and Bickhard (2018) showed recently that at 4 years but not before children start to be able to reflect on their activity on objects, catalyzing change in other domains, such as ToM, which requires reflection. However, using reflection to organize plans of behavior takes time. Specifically, Chevalier et al. (2015) showed that 5-year-old children do not but 10-year olds do spontaneously engage in proactive control of their behavior. The crucial factor in this development was metacognitive awareness rather than working memory or shifting. Finally, reasoning development (Moshman, 2015) and rational choices in decision making (Amsel et al., 2008) are based on increasing awareness of the inferential processes involved which allows systematic manipulations of information in reasoning arguments, such as modus ponens, modus tollens, or fallacies. Along this line, training awareness of logical schemes involved in reasoning tasks and constructing related mental models accelerated reasoning development (Christoforides, Spanoudis, & Demetriou, 2016). In short, this research suggests that cognizance is a central factor running through all levels of functioning noted at the beginning.

1.2. Relations between processes in successive representational cycles

Integrating over a long tradition of theory and research on cognitive development (e.g., Case, 1992; Kail & Ferrer, 2007; Mosham, 2015; Pascual-Leone, 1988; Piaget, 1970, 2001; Wellman, 2014), Demetriou and Spanoudis (2018), Demetriou et al., 2018 suggested that cognitive development occurs in four cycles, with an early and a late phase in each: episodic representations from birth to 2 years (remembrances of actions and experiences preserving their spatial and time properties); realistic mental representations from 2 to 6 years (blueprints of episodic representations where spatial and time properties are reduced, associated with symbols, such as words or mental images); generic rules organizing representations into conceptual/action systems from 6 to 11 years, (e.g., conceptual categories; causal models, etc.); and overarching principles integrating rules into systems where truth may be evaluated, from 11 to 16 years.

These cycles are not developmental stages in the traditional sense. That is, they do not presume cycle-specific homogeneity of performance across conceptual domains. They only presume that a certain kind of representations emerge and dominate in each cycle. However, mastery may vary extensively across domains because reasoning and knowledge domains are distinct “mental languages” to be learned and practiced as such (e.g., mental rotation, sorting, arithmetic operations, and hypothesis testing in spatial, categorical, quantitative, and causal reasoning, respectively) (Demetriou & Mouyi, 2011). Thus, the notion of cycles exists together with the assumption of continuous developmental change which drives extant representations to rise to the highest level possible in the cycle thereby preparing their transformation into the representations of the next cycle. Under this assumption, in Darwinian terms, cycle-specific representational kinds allow understanding of the world at a particular level of sophistication. Their change inheres in an ever-present, partially cognized, abstraction process which generates representational species of increasing relational depth: for instance, property-based aggregates of objects, exemplar-based representations of object groups, rule-based categories organizing representations, and logical set-like principles constraining rule relations at the four cycles, respectively. Note that there is no mention of “concreteness” or “formality” of thought at different phases of development. Concrete elements in representations and formalization of abstraction are always present: episodic representations are redefined and formalized in realistic representations; these are formalized in rule-based representations which are finally formalized in principle-based representations.

Cognizance is an integral component of this abstraction processes in all development across cycles. It emerges from the cognitive and behavioral processes dominating in each cycle and participates in their transformation in the processes of the next cycle. Thus, at the beginning of cycles cognizance captures the new forms of representation emerging; at the end of the cycle it yields insight into underlying relations which generates the representations of the next cycle. Therefore, cognizance of the dominant representations and processes in each cycle beyond a minimum (yet to be specified) level of refinement is a major transition mechanism to the next cycle (Demetriou & Spanoudis, 2018; Demetriou et al., 2018). This study focuses on the cycles of realistic representations and rule-based thought.

From 2–4 years, children control simple behavioral sequences, such as repeating self-initiated action episodes (e.g., bathing their doll or bringing shoes to father). In reasoning, they may translate representational ensembles into reasoning sequences (e.g., “uncle's car is outside, so he is in”) forming the background of reasoning schemes, such as modus ponens (i.e., if A then B; A, thus B). Cognizance is aligned with this cognitive content. Toddlers are aware of the perceptual or behavioral aspects of their experiences (e.g., I remember what I saw before; Paulus, Proust, & Sodian, 2013). At preschool, from 4 to 6 years, representations are differentiated and explicitly cognized; thus, for instance, one's own representations may be contrasted with another person's representations vis-à-vis each person's perceptual access; ToM is an index of this possibility. Concomitantly, preschoolers are in control of attentional focus, shifting between actions according to instructions (e.g., “Sort objects according to color when a red tag is on and according to shape when a square tag is on”). In reasoning, pragmatic inferences scaffold mental exchanges between persons and behavioral possibilities and expectations (e.g., “You said I can play outside if I eat my food; I ate my food; I go to play outside”).

At 6–8 years of age, representations are linked by explicitly represented rules. For instance, children explicitly differentiate between easy and difficult memorization tasks and associate them with differences in the effort needed, suggesting awareness of the relation between complexity of representations and learning. Executive control of behavior conforms to rule-based action plans, such as turn-taking in games. Inference develops into scheme-based reasoning mastering basic syllogistic schemes, such as modus ponens, conjunction and disjunction. At 8–10 years, children may explicitly differentiate between mental processes and shift between them (e.g., to remember you need to observe carefully and rehearse; to sort you need to follow a sorting rule). Also, in this phase children differentiate between the metaphorical and literal meaning of verbal statements (Carpendale & Chandler, 1996) and grasp second-order ToM (e.g., “Mary thinks that Helen thinks that …”). Thus, in this phase, executive control is upgraded into a conceptual fluency program allowing children to shift between mental processes (e.g., memory vs. inference) or conceptual domains (e.g., they recall words belonging to different categories—fruits, animals, furniture—following a probe). Finally, reasoning integrates reasoning schemes into reasoning systems. Symmetric conditional reasoning, dominating in this phase, where modus ponens is considered symmetric with modus tollens indicates, despite its weakness, that relations between inferential processes are recognized (e.g., “If there is an apple there is a pear; there is an apple, so there is a pear; there is not a pear, so there is not an apple.”)

1.3. The present study: predictions

This study is part of broader project exploring the interaction between various aspects of cognizance, executive control, and reasoning in development from preschool to adolescence (Demetriou, Makris et al., 2018; Kazi et al., 2012; Makris et al., 2017; Spanoudis, Demetriou, Kazi, Giorgala, & Zenonos, 2015). This study involved children operating at the second phase of realistic representations (4–6 years) and the two phases of rule-based representations (6–10 years). These children were examined by executive, cognizance, and reasoning tasks. Executive tasks addressed inhibition, flexibility in shifting, and working memory. Cognizance was examined by tasks addressed to awareness of perceptual and inferential origins of knowledge, first- and second-order ToM, and awareness of similarities and differences between cognitive processes and their possible mental load. Inductive reasoning was examined by a Raven-like battery requiring integration of 1, 2, and 3 dimensions; deductive reasoning was examined by three syllogisms tapping modus ponens, conjunction, and disjunction. Based on the literature above, we test the following predictions:

1 To reveal how cognizance mediates between executive and reasoning processes, tasks would have to scale as expected based on their representational profile. That is, perceptual awareness and first-order ToM would scale lower than inferential awareness and second-order ToM; also, lower level deductive (e.g., modus ponens) and inductive Raven-like (e.g. level A) reasoning items would scale lower than more demanding items (e.g., disjunction or level C Raven-like items). Mastering these scales would extend throughout the age period examined. This would allow testing a spiral relation between cognizance and the other processes such that the grasp of awareness at one phase opens the way for the up grating of the other phases which generates new awareness and so on.

2 A hierarchical model where the various processes emerge as separate constructs related to a higher-order general construct (g) would express performance on the tasks better than models involving only process-specific *or* g constructs. This would reflect both the common core shared by the various processes and their relative autonomy.

3 Cognizance would be a powerful proxy of g, to reflect its role as an orchestrating and change force of the specialized processes it interacts with. As such, it would appear as a relay center mediating between executive and reasoning processes over the period of time between the two testing waves.

4 The predictive power of different cognizance components is a function of their relevance to the cognitive task at hand. Therefore, predicting change in reasoning would be related more to the awareness of cognitive processes involved in reasoning rather than awareness in ToM, which is more related to social problem solving. Therefore, in the present study, (i) awareness of cognitive processes would be a stronger predictor of change in reasoning processes than ToM. (ii) Also, cognizance mediation is phase-specific, based on perceptual awareness in the phase of realistic representations, from 4 to 6 years, and on inferential and process awareness during the construction of rule-based thought, from 6 to 10 years.

5 In development, g would appear as a double-face construct: in addition to time-specific g reflecting the overall state of mental possibilities at a given time, change-specific g is necessary to stand for the general dynamics of change (g_{ch}). This g_{ch} would capture the operation of forces triggering change in many specific processes when activated. There may be many such forces. In terms of the present approach, a change in cognizance yields new insights in inter-relating representations and metarepresenting relations that generalizes across domains. Practically, this assumption implies that individual differences in the state of ability at a given time *t* does not fully constrain individual differences in patterns or rate of change during a time window between *t* and *t* + 1.

2. Method

2.1. Participants

A total of 113 children, about equally drawn among 4- (N = 37, 18 girls; mean = 4.84; SD = .42), 6- (N = 40, 19 girls; mean = 6.48; SD = .45), and 8-year-old children (N = 36, girls = 16; mean = 8.42; SD = .26) at first testing, were tested twice; the second testing took place two years later (January-March in 2015 and 2017, respectively). Attrition was low (< 5 children). These children were sampled from schools in Athens, the capital of Greece, and the island of Crete. They all came from upper middle-class background, with at least one of the parents having university education. Examining children from this socio-economic status group of the population aimed to minimize the possible negative influence of adverse socio-economic conditions on the development and interaction between the processes of interest, which is the primary aim of this study.

2.2. Tasks

2.2.1. Executive control

Executive control tasks addressed by three types of tasks: attention control, flexibility in shifting, and working memory. They were as follows:

Attention control tasks required perceptual discrimination and inhibition. Specifically, three sets of object pairs were presented on the two sides of the screen: (a) identical (i.e., two equal sets of dots, two identical objects or two identical geometrical figures), (b) similar (i.e., two different arrangements of the same number of dots, the same object in two different appearances, such as two visually different glasses, and the same geometrical figure oriented differently), or (c) different from each other. Participants chose the “same” key on an SR-Box when the configuration was either identical or similar and the “different” key when the configuration was different. Each set included 24 trials. Reaction times to correct responses to the sets b and c above were used (i.e., higher than 80% in all tasks but one) because they require stimulus discrimination and response selection to a goal-relevant stimulus.

Cognitive flexibility was examined by the Lexical Stroop Sort picture-word task (LSST) (Wilbourn, Kurtz, & Kallia, 2012). Children were concurrently presented the picture of a colored object (e.g., a "white bed") and an acoustic label, naming an object or a color. Labels might correctly name the object shown (e.g., "bed"), its color, (e.g., "white") or an irrelevant object (e.g., "table") or color (e.g., "black). Children were asked to decide as fast as possible if the label named the identity of the object (by choosing an object face), its color (by choosing a color face), or none (by choosing a "cheating" face). Thus, this task tested how flexibly children might pair labels with picture properties. This task included a set of training trials and 20 test trials. Reaction times were used. Alpha reliability for the two sets together was 0.86 and 0.88 for the two testing waves, respectively.

Working memory was examined by two tasks, backward word- and backward digit-recall task. There were five levels of difficulty in each task requiring backward recall of 2–6 digits or words; there were six sets in each difficulty level. Mean level score was the highest level where 2/3 of the items were successfully recalled. Alpha reliability for the two tasks was 0.84 and 0.86 for the two testing waves, respectively.

2.2.2. Cognitive tasks

2.2.2.1. Inductive reasoning. A Raven-like matrix test including 18 matrices addressed inductive reasoning at three levels of complexity, requiring abstraction of one, two, and three dimensions, respectively. Specifically, items at the first level involved a single dimension and required to uncover the pattern defining this dimension (same color-same size, increasing size, same size-alternating color). At the second level, 2-dimensional 3 × 3 matrices required to conceive of the intersection between two dimensions (e.g., animal and color, animal and size, color and size). At the third level 2-dimensional 3 × 3 matrices involved three dimensions (color, shape and size, animal, color, and size, and activity, color, and size). The missing item was chosen among six choices. Items were scored on a pass-fail basis (0 for wrong and 1 for correct choices) and level scores were obtained by adding across level-specific items. Examples of the three levels are presented in Fig. 1.

2.2.2.2. Deductive reasoning tasks. These tasks required to map permission rules onto their relevant pictorial representation (Goswami, 2002). Modus ponens, conjunction, and disjunction arguments were given. There was a story for each logical scheme: Modus ponens: "If Sally wants to play outside, she must put her coat on"; conjunction: "If she wants to play outside, the weather must be nice and her room must be tidy"; disjunction: "She can have either watermelon or banana, only if she eats her lunch." for the three logical schemes, respectively. Children had to repeat the rule and choose, among four cards, the card showing Sally obeying the rule. Performance on each item was scored from 0 to 3 to reflect understanding of the rule and its matching with the proper pictorial representation (based on both picture selection and explanations): 0 for both wrong choice of picture and failure to repeat the rule; 1 for choosing the right picture but failing to repeat the premises of the rule or for choosing a wrong picture but correctly repeating the premises; 2 for choosing the right picture and partially repeating the rule; 3 for choosing the right picture and fully repeating the rule. Repeating the rule was required to ensure that correct card selection was not accidental. Alpha reliability for the deductive and inductive reasoning tasks together was .51 and .67 for the two testing waves, respectively.

2.2.3. Cognizance

2.2.3.1. Perceptual and inferential awareness (PIA). A new task examined awareness of perceptual and inferential origins of knowledge. Two short videos showed a child watching a teacher placing differently colored toy cars (red, green, and blue) into color-matching boxes (red, green, and blue, respectively). Visual, acoustic, and inference-based information was systematically manipulated as source of the protagonist's knowledge. The first video examined children's ability to differentiate vision, hearing, and inference as sources of knowledge. In this video, the teacher and the protagonist (John) sat next to each other. The teacher first named the cars ("We have a red, a green, and a blue car) and then the boxes ("We have a red, a green, a blue, and a white box) from left to right. Then, she placed the red car in the red box, while *also verbally describing her action* ("I put the red car in the red box").

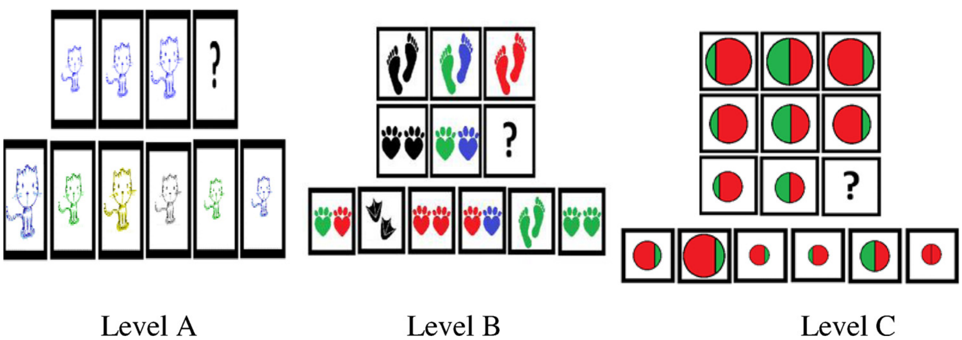

Fig. 1. Examples of Figures used in the Raven-like matrices test.
Note: Note that one (size), two (shape and color), and three dimensions (size, relative size of are covered by each color, and position of the one color relative to the other) were involved in Level A, B, and C, respectively.

Then she placed the green car in the green box, *but she did not describe this action*. Then, John went away. Thus, John *saw and heard where the red car was placed, saw but did not hear where the green car was placed, and he neither saw nor heard where the blue one was placed.* He later came back and was asked to specify where each car was placed; participants were asked if John knows where each car is, explain why, and explain the teacher's reason for placing the blue car in the blue box.

The second video aimed to differentiate *hearing from inference.* Here, the protagonist (Ann) sat across the table in front of rather than next to the teacher. After naming all objects as above, the teacher raised a wooden separation between them so that the protagonist *cannot see what she did*. She described her actions only while placing the red car in the red box ("I now put the red car in the red box"). She made no reference to the green or the blue car. Ann went away and came back later. She was asked to find where each car was located and explain why.

In the first task, answers about the red and the green car reflected perceptual awareness; answers about the blue car reflected inferential awareness. In the second task, answers about the red car reflected perceptual awareness; answers about the green and the blue car reflected inferential awareness. These tasks resemble the tasks used by Wimmer, Hogrefe, and Perner (1988)) to examine if children understand that perception (seeing) is a source of knowledge in that they all examine if children recognize that to know what is in a box one must either see or be told about the box's content. The present tasks examine, additionally, if children also recognize inference as a source of knowledge.

Responses to perceptual awareness questions were scored on a pass-fail basis reflecting both correct choice of box and an explanation indicating vision and/or hearing as the origin of the protagonist's knowledge (e.g., John saw where it was placed; Ann heard the teacher saying where it was placed"). The blue car can only be located by inference in both tasks. Answers to these items were scored on a 4-point scale, ranging from irrelevant or "don't know" responses (0) or color matching (1) (e.g., "It is in the blue box because they have the same color) to answers indicating a grasp of classification (2) (e.g., "Teacher placed cars in same-color boxes") and explicit awareness of mental processes (3) (e.g., "He thought (supposed, guessed) so, because the teacher sorted them according to color") (Spanoudis et al., 2015).

2.2.3.2. First-order ToM. The classical Sally-Ann task was used to examine first-order ToM (the participant specifies if Sally looks for an object according to her own or the participant's knowledge where it was placed). In this task, participants were asked to specify where a character would look for an object, in the place this character saw the object initially placed (correct but false belief) or in the place where the object was moved unbeknown for the character but known to the participant (wrong, indicating lack of ToM) (Wimmer & Perner, 1983).

2.2.3.3. Second-order ToM. Based on a task first presented by Perner and Wimmer (1985), in the second-order ToM task participants specified where two children would look for each other given the information they had for each other's whereabouts. Specifically, participants saw a video showing two characters, George and Helen, who wanted to buy ice cream from an ice cream street seller who was in the park. Helen did not have any money and thus she goes home to get money and return back because the ice cream seller told them he will stay in the park. After Helen left, the ice-cream seller told George that he is moving to the church where there are more people. In his way to the church he meets Helen and he informs her that he is going to the church. Thus, after having the money, Helen goes to find the ice cream seller at the church; George goes to Helen's house, where Helen's mother told him that Helen went to buy ice cream. George knows where the ice cream seller went (church) but he thinks that Helen thinks that the ice cream seller is in the park. Helen knows where the ice cream seller is (church) but she thinks that George thinks that she thinks that the seller is in the park. Participants are asked to specify where George would look for Helen (first-order ToM) and where Helen thinks that George would think that Helen would go and justify their answers (second-order ToM) (Perner, 1993; Wellman, 2014). Alpha reliability for all perceptual/inferential awareness and ToM tasks together was .77 and .74 for the two testing waves, respectively.

2.2.3.4. Awareness of cognitive processes (ACoP). Children evaluated the similarity and relative difficulty of six task-pairs, three requiring comparisons of similar (both addressed to deductive reasoning, inductive reasoning, and ToM) and three requiring comparisons of different processes (deductive vs. inductive reasoning; inductive reasoning vs. ToM; deductive reasoning vs. ToM). Six pairs of pictures were presented to the children: (a) the two deductive reasoning tasks, (pictures 1 and 2); (b) the two inductive reasoning tasks (pictures 3 and 4); (c) the two ToM tasks (pictures 5 and 6); (d) the easy deductive and the easy inductive reasoning tasks (pictures 1 and 3); (e) the easy deductive and the ToM tasks (pictures 1 and 5); and (f) the easy inductive and the easy ToM tasks (pictures 3 and 5).

To engage the participants in reflection about the mental activities of the children depicted in the pictures, the experimenter presented the tasks as follows: "These pictures show two children. Their teacher asked them to do some work. In this picture, the teacher asked this child to XXX (pointing accordingly). In this picture, the teacher asked this child to XXX" (pointing accordingly). Children were first asked to describe each picture in order to focus on the activities concerned. They were then asked to answer the following two questions: "Who of the two children is doing the *easier* job?" and "Is the job of *this* child the same as the job of *this* child?" (pointing accordingly). The same procedure was implemented for all six pairs. Thus, twelve scores (six difficulty estimations and six similarity estimations) were obtained. The presentation order of the six pairs of cards was randomized.

Comparisons of similarity and difficulty were scored as follows: 0 for wrong or irrelevant responses; 1 for answers referring to (or comparing) the perceptual similarity of the objects involved (e.g., "there are the same kind of cubes in the two pictures"; "the cube in this picture is similar to the square in this picture"); 2 for answers referring to (or comparing) the symbolic/generic characteristics of the tasks (e.g., "here he has cubes and here he has a figure to work on"; "cubes are easier than pictures"); 3 for answers explicitly referring to the mental operation or processes involved (e.g., "they are both XXX"; "one is XXX, the other is XXX"; "it's easier to XXX than XXX"; it's easier to XXX than to XXX, because once you have learnt how to XXX, you remember it for ever"; "it's easier to XXX than to XXX, because when you XXX you must be more careful not to make a mistake") (Demetriou & Kazi, 2001, 2006). This scoring reflects increasing levels of awareness about the cognitive processes involved in the tasks. Alpha reliability for the 12 tasks involved in this set was .88 and .83 for the two testing waves, respectively.

Attention is drawn to the differences between the three sets of tasks above. The perceptual/inferential awareness tasks tested if children were aware that knowledge may originate from perception or inference, which may be used, by extrapolation, to fill in lags in information, given a specific action-perception pattern. ToM tasks test if children differentiate between their own and another person's mental state in reference to how each was perceptually connected to the world. The awareness of cognitive processes tasks required a more refined awareness of cognitive processes allowing their differentiation in character or mental demand. Therefore, ToM tasks are closer to *perceptual* awareness tasks as they both require an awareness that perceptions generate mental states; awareness of cognitive processes tasks are closer to *inferential* awareness tasks as they both require awareness of mental processes as such.

Inter-rater reliability across all cognitive and self-awareness tasks was very high (mean inter-rater agreement was 98%).

2.3. Procedure

The presentation of all tasks was computer-based, using the e-prime environment. Children were individually tested on all tasks by the same experimenter at both testing waves (the second author); testing took place in an especially provided room at each school. Presentation order of tasks was counterbalanced across children and testing sessions; however, presentation order within sessions was fixed, following increasing task difficulty. Total testing time was approximately 150 min, split in several sessions. The time of testing sessions varied with age: 4-, 6-, 8- and 10-years old children were tested in 10-, 15-, and 20-minute sessions, respectively. Each child received only one session/day. Instructions were given orally, and it was ensured that children were engaged in the process. The study was approved by the Research Committee of the Greek Ministry of Education (Φ15/888/210943/Δ1).

2.4. Statistical analysis

This is a complex study aiming to answer developmental and organizational questions about the processes of interest. Thus, different methods were used to answer the various questions of interest. To specify the developmental scaling of cognizance and reasoning tasks, Rasch scaling was used; this is the method of choice to rank-order performance on tasks systematically varying in difficulty and specify the task and person place on a task hierarchy (Wright & Masters, 1982). In turn, individual scores obtained on the integrated Rasch scales were subjected to an ANOVA to specify developmental and individual differences across scales. A power analysis using the Gpower computer program (see Erdfelder et al., 1996) indicated that a total sample size of 100 people would be needed to detect medium effects (effect size $F = .25$) with 80% power using an F test with alpha at .05. Thus, it is unlikely that our findings below can be attributed to a limited sample size.

To specify the organization of mental processes structural equation modeling (SEM) was used; SEM is the method of choice for uncovering latent constructs from performance on individual tasks and testing predictions about their relations (Bentler, 2006). To specify change in time across testing waves latent score change modeling (McArdle & Nesselroade, 2014) and latent transition analysis (Muthen & Asparouhov, 2011) were used. These are methods specifically developed to model change over time in longitudinal studies. A statistical power analysis was performed for sample size estimation for both SEM models using MacCallum–-Browne–Sugawara (MBS) method (MacCallum, Browne, & Sugawara, 1996). Our estimation was based on Preacher and Coffman (2006) on-line utility for RMSEA based sample size computation. We tested the two models (SEM and LCSM) using exact fit hypothesis (see Kim, 2005); thus, for the SEM model we use $df = 314$, $\varepsilon 0 = 0$, $\varepsilon a = .05$, desired power = .90, and $\alpha = .05$ and for LCSM model $df = 601$, $\varepsilon 0 = 0$, $\varepsilon a = .05$, desired power = .90, and $\alpha = .05$. The first power analysis yielded a minimum sample size of $n = 105$ and the second one of $n = 74$. Therefore, the models to be presented below are powerful vis-à-vis their aims.

It is noted that preliminary analyses suggested no differences between genders either in development or organization of the processes examined. Thus, genders were pulled together in all analyses presented below.

3. Results

3.1. Development

Table 1 shows percent success on the various tasks across the two testing waves. It appears that an intuitive grasp of the foundations of deductive reasoning was present at 4 years: many of the 4-years old children responded correctly on the modus ponens (78%) and the conjunction task (54%), although many of them failed to fully recall the relevant rule; this proved possible only at 6 years for modus ponens and disjunction and at 8 years for conjunction. Also, Raven level A (67% of 4-year-old children at first wave) and perceptual awareness (75% of 4-year-old children at second wave, when they are 6-years old) can be credited to 4–6-year-old children as a group. First-order ToM was within the ability of a minority of children at 4 years (32%); however, awareness of cognitive processes and second-order ToM were clearly beyond the ability of children at this age. At the age of 6–8 years all three schemes of deductive reasoning, level B of inductive reasoning as addressed by the Raven-like test and first-order ToM were well established. By the age of 10 years most processes were well consolidated, including awareness of cognitive processes. However, second-order ToM (42% at the age of 10 years) and level C Raven matrices (47%) were still beyond mastery by the majority of

Table 1
Percent success on tasks across age and testing waves.

Age	MP	Conjunct	Disjunct	Rav A	Rav B	Rav C	Percept. Awareness	Inferent. Awareness	Process evaluation	Difficulty evaluation	ToM 1storder	ToM 2ndorder
4												
Wave1	40 (78)	38 (54)	35 (49)	67	43	28	49	1	6	2	32	8
Wave2	38 (78)	3 (76)	32 (76)	74	52	21	75	2	17	2	32	8
6												
Wave1	65 (80)	38 (52)	62 (85)	68	63	28	59	5	28	15	32	8
Wave2	78 (94)	62 (85)	70 (90)	75	55	20	70	36	23	33	65	32
8												
Wave1	86 (92)	67 (80)	89 (85)	82	75	37	86	15	55	38	72	39
Wave2	92(95)	69 (78)	89 (87)	86	82	47	85	49	64	62	97	42

Note: Success on deductive reasoning items stands for obtaining the highest score on each task; (correct performance but partial recall of the rule is shown in parenthesis). Success on Raven tasks of each difficulty level stands for mean percentage success on the six items of each difficulty level. Success on perceptual and inferential awareness tasks stands for mean success (score 2 or above) on the respective items. Success on similarity and difficulty evaluation stands for mean success on the respective set of six similarity and difficulty evaluation tasks (score of 3 or 4).

children at second wave when they were 10-years old.

To examine the possible influence of age, testing wave, and mental processes, all cognizance and all reasoning tasks were Rasch scaled separately at each testing wave. Specifically, 22 cognizance (3 perceptual awareness, 3 inferential awareness, 2 first-order and 2

second-order ToM, 6 awareness of similarity and 6 awareness of mental load items) and 21 reasoning items (the 18 Raven-like Matrices and the three pragmatic reasoning tasks) were scaled at each testing wave. To ensure comparability of performance across scales and testing waves, all scales were fixed to vary from 1 to 5 (for each logit unit) with a mean of 3 for both persons and items. All four scales proved to be very reliable (all infit and outfit measures varied between .92 and 1.09; all item separation indexes > 4.14; all item reliabilities > .95). Fig. 2 shows how the various items were scaled. In cognizance, perceptual awareness, first-order ToM, and awareness of similarities of tasks involving different processes (reasoning and ToM) scaled at the bottom end (easy) of the scale. Differentiation of mental load between ToM, on the one hand, and inductive or deductive reasoning, on the other hand, inferential awareness, and second-order ToM scaled at the top (difficult) of the scale. In reasoning, all level A Raven-like matrices scaled at the bottom and all level C Raven-like matrices scaled at the top of the scale. Deductive reasoning scaled in the middle, together with level B matrices, with modus ponens being the easiest and conjunction being the most difficult of them. Item scaling did not basically differ across testing waves.

The high consistency and reliability of the two scales allows using them for comparative purposes. Thus, the individual logit scores obtained on the two scales were subjected to a 3 (the three age groups) x 2 (the two testing waves) x 2 (cognizance vs reasoning) repeated measures ANOVA. The effects of age, $F(2,110) = 159{,}59$, $\eta_p^2 = .74$, wave, $F(1,110) = 58{,}54$, $\eta_p^2 = .35$, and cognitive process, $F(2,110) = 292{,}52$, $\eta_p^2 = .73$ (observed power = 1 in all cases) were highly significant and very strong. These results suggested that performance increased across age at first wave at 4, 6, and 8 years and improved extensively from first to second testing wave when children were 6-, 8-, and 10-years old. Noticeably performance on reasoning was higher than on cognizance; however, the significant process x age interaction, $F(2,110) = 19.74$, $\eta_p^2 = .26$, power = 1.00, indicated that the difference between reasoning and cognizance decreased systematically across the three age groups; the process x wave, $F(1,110) = 23{,}22$, $\eta_p^2 = .17$, power = 1.00, interaction indicated that improvement in cognizance was larger than in reasoning (see Fig. 3).

Overall, the success patterns on the various tasks, together with the scaling of the various tasks presented above, suggest, in agreement with our first prediction, that lower levels of reasoning were associated with perceptual awareness; with development and

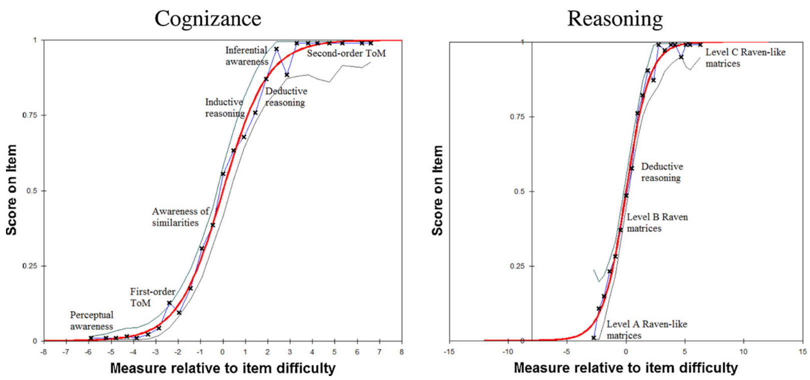

Fig. 2. Rasch scaling of cognizance and reasoning items at first wave.

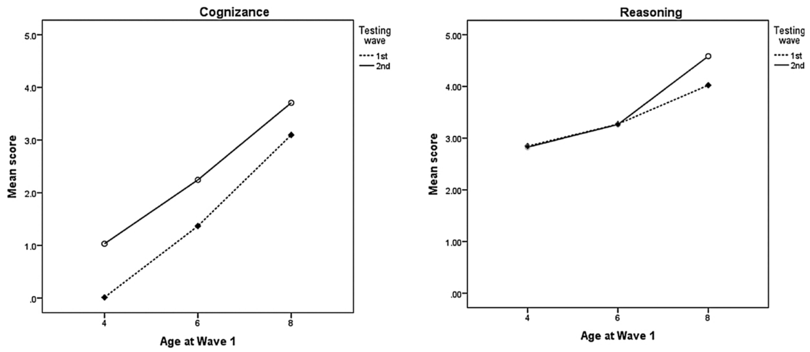

Fig. 3. Performance on the Rasch scales for cognizance and reasoning across age and testing waves.

mastery of more complex reasoning patterns, awareness became more refined, mapping inferential patterns themselves and their procedural and demand similarities and differences. The analyses below explore how these attainments interact in development causing changes to each other.

3.2. *Structure and relations between processes*

To test our second prediction, a series of confirmatory factor analysis and structural equation models examined the organization of the various processes at the two testing waves. These models included scores as follows: two scores for Attention Control (AttC; no flexibility score was included in these models because they were largely colinear with AttC scores), two for Working Memory (WM; backward word and digit span), a sum score standing for performance on Perceptual Awareness and a sum score standing for performance on Inferential Awareness (IA), three for ToM (first-, second-order ToM, and explanation), Awareness of Cognitive Processes (ACP; similarity between the cognitive processes of the tasks involved), three for Deductive Reasoning (DR; the three pragmatic reasoning tasks), and three for Inductive Reasoning (IR; sum scores for the three Raven-like levels) at each testing wave. It is noted that an attempt was made to reduce the number of scores involved in SEM because of the relatively limited sample size. The correlations between these variables are presented in Table 1 in Supplementary Material.

A background first model involved only one factor for each testing wave associated with all scores above; the second wave factor was regressed on the first wave. The fit of this model was poor, χ^2 (660) = 1511.31, CFI = .46, RMSEA = .11 (.10–.11), AIC = 191.306. A second model involved a separate factor for the sets of score mentioned above: i.e., a factor for Attention Control (AttC), Working Memory (WM), Perceptual-Inferential Awareness, Theory of Mind (ToM), Awareness of Cognitive Processes (ACP), Deductive Reasoning (DR), and Inductive Reasoning (IR). The task-factor relations across waves were constrained to be equal to ensure that factors were similarly identified across waves. All first-order factors of each wave were related to a second-order general factor (g1 and g2). At a first test of this model, these second-order factors were not related. The fit of this model, although still poor, was better than the fit of the first model, χ^2 (697) = 1362.43, CFI = .63, RMSEA = .093 (.085–.100), AIC = -31.57. At a next run, g2 was regressed on g1 to capture relations between testing waves; the fit of this model improved considerably, χ^2 (696) = 1230.54, CFI = .71, RMSEA = .083 (.075–.090), AIC = -161.46; the relation between the two factors was 1.

Altogether, the three models suggested, in line with the second prediction, that the various processes involved were discrete from each other, preserving their identity over time; also, they were related to each other via a general coordinating function represented by the general factor, which spans over time. However, the relatively weak fit of the last model suggested that there were more differentiated relations within and across waves than those captured by the two general factors and their direct relation.

To uncover these relations, a new model was tested aiming to uncover the possible relations between processes across testing waves. The following structural relations were built into the model: g2 was regressed on g1; also, each of the seven second-wave first-order factors was regressed on the *residuals* of all first-wave first-order factors; these relations captured how each process at second wave was affected by what is specific in each process at first wave which was not already accounted for by the relations between the two general factors. The fit of this model was acceptable and clearly better than the fit of all models above, χ^2 (607) = 786.66, CFI = .89, RMSEA = .052 (.040–.061), AIC = -427.34. Expectedly, some of the relations between first-wave residual factors and second-wave factors were non-significant. Following Walt test for dropping parameters, non-significant relations were dropped, resulting to a perfect model fit, χ^2 (637) = 819.79, CFI = .99, RMSEA = .051 (.040–.060), AIC = -454.21.

Expectedly, all self-regressions were high (all but one $\beta > .5$). Additionally, all processes but attention control were significantly related to several other processes. Specifically, working memory was related to perceptual/inferential awareness (β = .57), ToM (β = .17), and inductive reasoning (β = .24). Inductive reasoning was related to perceptual/inferential awareness (β = .48), and ToM (β = .23). Deductive reasoning was related to attention control (β = .24), working memory (β = .27), and perceptual/inferential awareness (β = .13). Perceptual/inferential awareness was related to attention control (β = .23) and working memory (β = .43). ToM was related to attention control (β = .24) and working memory (β = .30). Awareness of cognitive processes was related to attention control (β = .38), ToM (β = .17), and inductive reasoning (β = .58). This pattern of relations indicates, on the one hand, that cognizance processes at second wave drew on attention control and working memory processes at first wave; on the

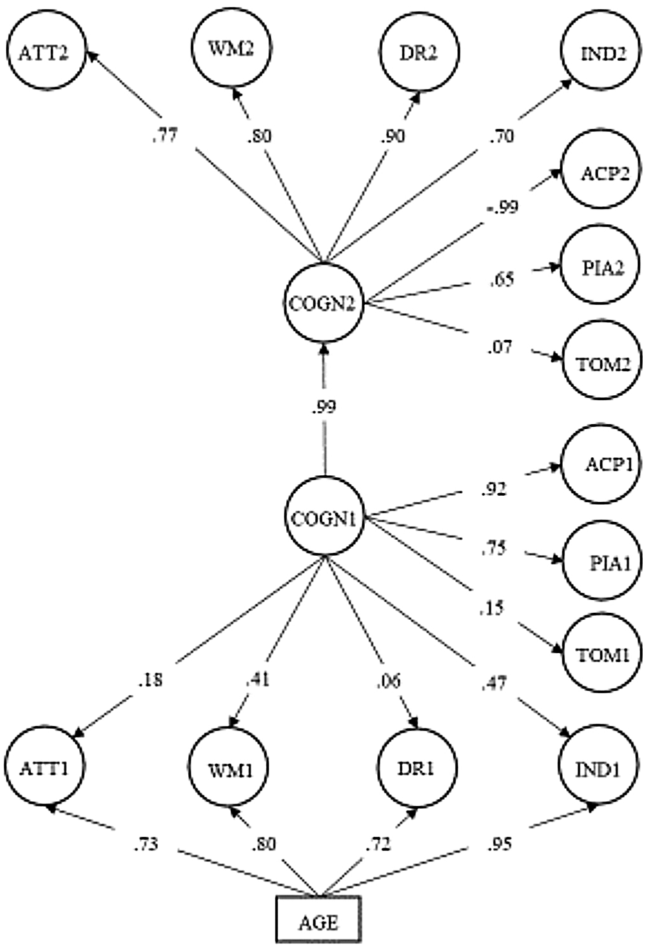

Fig. 4. The mediation model showing how cognizance mediates between all other factors from first to second testing wave.
Note: Only relations between factors are shown in Fig. 4. The full model is presented in Table 3 in Supplementary Material. The symbols Att, WM, Dr, and IND stand for attention control, working memory, deductive and inductive reasoning, respectively; the symbols ACP, PIA, and ToM stand for awareness of cognitive processes, perceptual/inferential awareness and theory of mind, respectively; numbers 1 and 2 stand for first and second testing wave, respectively.

other hand, all representational and inferential processes represented by working memory and reasoning at second testing drew on cognizance processes at first wave. Therefore, it was suggested, in agreement with the third prediction, that cognizance mediates between executive and reasoning processes.

To directly test this assumption, a specific model was designed specifying how cognizance transfers effects from executive and reasoning factors at first wave to executive and reasoning factors at second wave. The following relations between factors were built into this model: first, attention control, working memory, inductive reasoning, and deductive reasoning at first wave were regressed on age to capture developmental effects. The three awareness factors (perceptual/inferential awareness, awareness of cognitive processes, and ToM) at first wave were regressed on a second-order cognizance factor; the corresponding factors at second wave were also regressed on a second-order cognizance factor. This factor was regressed on the first-wave cognizance factor. Attention control, working memory, deductive reasoning, and inductive reasoning at second wave were regressed on the second-wave cognizance factor. Therefore, it is assumed that cognizance operates as a mediator, carrying the effects of executive control and reasoning at first wave to cognizance at second wave which carries them to executive control and reasoning at second wave. The fit of this model was excellent, χ^2 (601) = 731.36, CFI = .95, RMSEA = .044 (.033–.055), AIC = -470.64. This model was compared with a model where executive control, (χ^2 (600) = 802.43, CFI = .93, RMSEA = .055 (.044–.064), AIC = -397.57), or reasoning, χ^2 (600) = 747.46, CFI = .95, RMSEA = .047 (.035–.057), AIC = -452.54), were raised to the level of the mediator. The fit of both models was weaker than the fit of the cognizance mediation model. This is the model presented in Fig. 4.

Inspection of Fig. 4 suggests the following conclusions. First, age is highly related to all processing efficiency and reasoning factors (all relations higher > .7). Attention control (β = .18), working memory (β = .41), and inductive reasoning (β = .47) related significantly to cognizance. The relation between first- and second-wave cognizance was extremely high (β = .99). Attention is drawn to the fact that the relation of ToM to this factor was low at both waves (< .15) as contrasted to the relation of both, perceptual/

inferential awareness and awareness of cognitive processes which was very high (all > .6). Noticeably, however, the relation of all second-wave factors to cognizance was very high (all > .7). This pattern of relations suggests that there was a very powerful general factor underlying relations between processes at each wave which is very stable across waves. Cognizance emerged as the strongest proxy for this factor. This is in agreement with third prediction. Also, in line with fourth prediction (4i), perceptual/inferential awareness and awareness of cognitive processes were better representatives of cognizance than ToM, reflecting the demands of inductive and deductive reasoning tasks used here.

3.3. Modeling change

3.3.1. latent change score models across processes

To model possible relations in change patterns across processes, Latent Change Score Modeling (LCSM) and Latent Transition Analysis (LTA) were employed. The first method allows examining relations between changes in various processes at various levels, from pairs of processes to groups of processes and their underlying commonalities. The second method allows focusing analysis on change of specific processes and specify the factors that possible drive change in them. These methods are particularly suitable for testing the predictions 4ii and 5.

LCSM is a case of structural equation modeling where the state and the degree of change in two or more processes Pij at a time t is mutually predicted by the condition of each of them and the other processes at an earlier time t - 1. There are various types of LCSM (see Kievit, Brandmaier, & Ziegler, 2018; McArdle & Nesselroade, 2014). In general, a model involving two processes P_i and Pj would include the following relations: first, performance in each process at time t is regressed on itself ($P_{it} \rightarrow P_{it\text{-}1}$) and the difference score ($\Delta P_i = P_{it} - P_{it\text{-}1}$, i.e., the change score) between this time and the previous time; second, the two change scores ΔP_i and ΔPj are regressed on the performance scores of both processes at time t -1; third, the two scores at the first time are regressed on an intercept factor to specify the means of the measures across time and the change scores are regressed on a slope factor to specify the rate of change; fourth, the two processes at time t -1 and the change scores at time t are correlated.

The findings presented above suggested that there is a strong common factor underlying change in the various processes. Thus, the LCSM tested aimed to disentangle how change in each process related to a possible common source or to its initial state observed at first testing. In sake of this aim, the models included one factor for each testing wave for the following processes: attention control, working memory, cognitive awareness (associated with perceptual/inferential awareness and awareness of cognitive processes), ToM, and reasoning (associated with deductive and inductive reasoning). There was also a latent score change factor for each process standing for the difference between first and second testing. To implement our fifth prediction which assumes the operation of two general factors, two general factors were created: (1) the g1 factor was a second-order factor associated with all five first-wave process specific factors; (2) the g_{ch} was a slope factor related to all first- and the second-wave measures. The relation of each first-wave measure with g_{ch} was constrained to 1; the relation of the corresponding second-wave measure with g_{ch} was constrained to 2. These values reflect the assumption that scores increased across waves in all processes. The correlations between the variables involved in these models are presented in Table 2 in Supplementary Material.

A first model tested the assumption that change in each process is a function of g1 only. To test this assumption, each for the five specific change factors was regressed on g1; these relations were let free to vary. The second-wave processes specific factors were regressed on g1 and g_{ch}; these relations were constrained to 1. Finally, g_{ch} was regressed on g1 to examine how the initial state of the general factor relates to the general trend for change. The fit of this model, although good, was not acceptable by all fit indexes, χ^2 (344) = 664.41, CFI = 1.00, RMSEA = .092 (.081–.102), AIC = -23.59; this reflected the low relations between g1 and all domain-specific change scores but one (all < .1). In a second model, the relations between the five specific change factors was regressed on g_{ch} only, dropping their relation with g1; the fit of this model was better, χ^2 (344) = 572.77, CFI = 1.00, RMSEA = .078 (.068–.088), AIC = -115.23; this reflected the fact that the relations between g_{ch} and each of the domain-specific factors were much higher (four of the five > .6). In a third model each of the domain-specific change score factors was regressed on both g1 and g_{ch}, but the g1-specific change scores relation was constrained to -1. This manipulation implemented the assumption, suggested by preliminary analysis examining pairwise relations between all possible pairs of processes, that the initial state of ability imposes a ceiling to the change possible. This manipulation resulted in a further improvement of the model fit, χ^2 (344) = 550.94, CFI = 1.00, RMSEA = .074 (.062–.085), AIC = -137.06. In a last model, each of the five latent change score factors was regressed, in addition to g1 and g_{ch} as above, on its corresponding first-wave factor; this addition resulted in a further improvement of the model fit, χ^2 (339) = 532.47, CFI = 1.00, RMSEA = .072 (.060–.083), AIC = -145.53. This is the model shown in Fig. 5.

It may be seen that all relations between g_{ch} and the domain-specific score factors were significant and high (all but one $\beta > .6$); notably, only two of the relations between specific change score factors and the corresponding first wave factors were significant, i.e., working memory, ($\beta = .44$), and metacognitive awareness ($\beta = .25$). Fig. 6 illustrates how the two general factors, g1 and g_{ch} operate as a ceiling and a developmental momentum factor, respectively, relative to the specialized factors. Panel A shows the negative relation between change and g1; Panels B–D show the positive relation between the general slope factor and each of the specialized change score factors. Obviously, these patterns are fully in line with our fifth prediction. Specifically, the size of change depends on distance from ceiling: the closer one is to this ceiling the less is the room for change left; however, the more away one is from this ceiling the more likely is that change will be fast and strong herding all processes to reach the ceiling.

3.3.2. Capturing transitions

Prediction 4ii claims that cognizance mediation is phase specific. The models below test this prediction, highlighting how developmental ceilings are penetrated. The developmental patterns discussed above indicated that level C Raven-like matrices represent

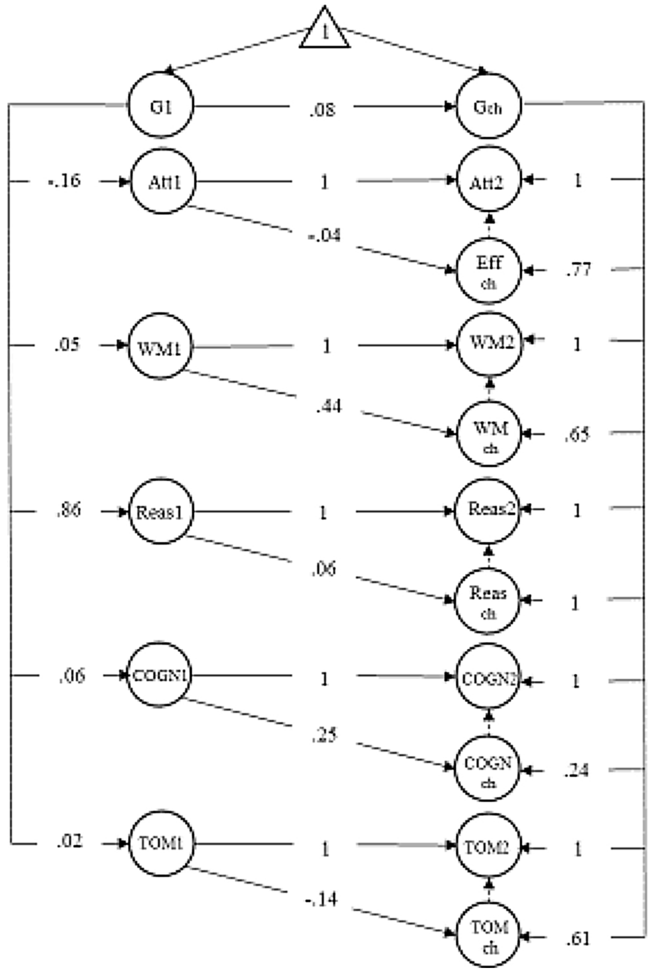

Fig. 5. Latent change score model including a general (G1) and a general change factor (Gch).
Note: The full model is presented in Table 5 in Supplementary Material. The symbols Att, WM, Reas, COGN, and ToM stand for attention control, working memory, reasoning, cognizance (perceptual-/inferential awareness and awareness of cognitive processes, and theory of mind, respectively. The relations between all change factors and G1 was constrained to -1.

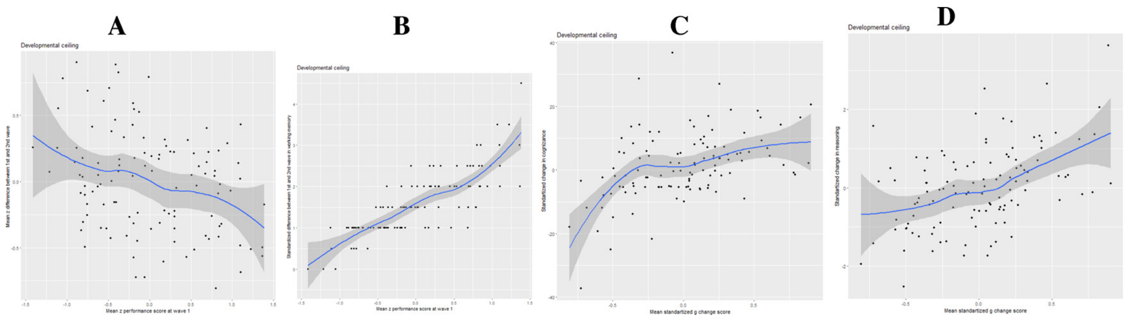

Fig. 6. A: Illustration of developmental ceiling (A) and developmental momentum (B–D).
Note: A: Mean standardized difference score between first and second testing wave as a function of mean z performance score at first testing: g (mean). B–D: Standardized difference score between first and second testing in working memory (B), cognizance (C) and reasoning (D) as a function of the factor score attained on the first principal component abstracted from all change scores.

a ceiling for the reasoning development in the age period examined here; second-order theory of mind and inferential awareness represent a ceiling in the development of cognizance. This is reflected in the fact that only a minority of the oldest children examined mastered these processes at the second testing wave, when they were 9.5 years old. It would be interesting to specify the factors causing the transition from lack of mastery to the mastery of these processes. To examine these transitions, Latent Transition Analysis

(LTA) was employed (Muthen & Asparouhov, 2011). LTA specifies how individuals move across categories in a period of interest and the factors possibly affecting this movement.

In the present model, only performance attained at first and second wave on the six level C Raven-like matrices were used. It is reminded that there were two classes of performance on these matrices, failure (class 1) and success (class 2). There were two latent categories, performance on the first and performance on the second wave. The question of interest here is to specify transition from class 1 of latent category at testing wave 1 to class 2 of latent category 2 at testing wave 2 and specify what influences this transition, if any. The model assumed measurement invariance across time for the six latent class indicators. Awareness of cognitive processes was used as a covariate. The categorical latent variable standing for performance at second testing was regressed on categorical latent variable standing for performance at first testing and the covariate; this allows to compare class 1 to class 2 at second testing. Also, this first wave latent variable was regressed on the covariate, allowing to compare class 2 with class 1 at first wave. The fit of this model was excellent, (Likelihood Ratio Chi-Square (4069) = 463.15, p = 1.0, AIC = 2191.14). We found that 38 (34%) children stayed in class 1 at both waves (failed); 28 (25%) transitioned from class 1 at first testing to class 2 at second testing (succeeded); 4 (3%) regressed from class 2 at wave 1 to class 1 of wave 2; 43 (38%) succeeded at both times. Thus, there was considerable probability of transition from not possessing to possessing the ability to solve level C matrices across the two testing waves (.43, odds = 1.75) and a very low probability to regress if already having this ability (.094, odds = .10). The effect of the covariate on latent class 2 was very high (9.30, $p < .005$), implying a huge difference between class 1 to class 2 at second testing in reference to awareness of cognitive processes. That is, the odds of transition from not possessing to possessing the ability of interest for every unit increase on awareness was 10919.35, suggesting that it was extremely likely to transition to level C Raven-like matrices than not transition, if awareness increased.

A second model tested the possible impact of reasoning on transition to inferential awareness and second-order ToM. In sake of this aim, performance on the inferential awareness and second-order ToM tasks was used. There were two classes, success and failure, on these tasks at the two testing waves, defining a latent variable for performance on each wave. In the fashion of the model above, the latent category at second testing was regressed on the corresponding category at first testing and, also, two covariates, mean performance on B level Raven matrices and mean performance on deductive reasoning tasks at first wave. The fit of this model was also excellent, (Likelihood Ratio Chi-Square (1007) = 94.74, p = 1.0, AIC = 1278.2014). In this model, 86 children operated in class 1 at both waves (failed, 61%), 27 moved from class 1 to class 2 (24%), and 27 (24%) operated in class 2 at both waves (succeeded); no one regressed from class 2 at first wave to class 1 at second wave. The transition probability to second-order cognizance was lower than above (.20, odds, .25). There was some influence of reasoning, Raven-like (.18, $p > .05$; odds = 1.19) and deductive (.49, $p > .05$; odds = 1.63) on this transition; however, this was small and non-significant.

The findings above suggest that the influence of cognizance on transition to higher level reasoning and the influence of reasoning on transition to higher level cognizance are not symmetric. The first is very powerful and the second weak. It might be the case, however, that reasoning influences development of cognizance at an earlier phase. To examine this possibility, the model above was re-designed to examine the contribution of lower level reasoning (level A of Raven and deductive reasoning) to the acquisition of awareness of the perceptual origins of knowledge and first-order ToM. In sake of this aim, latent categories for cognizance were specified in reference to performance on the three perceptual awareness tasks and the two first-order ToM tasks. Performance on level A Raven matrices and deductive reasoning were used as covariates, as specified above. In this model, the odds of transition to perceptual awareness and first-order ToM were rather low (probability .15; odds .18). However, the effect of deductive reasoning on this transition was significant and very high (2.26, $p < .5$; odds = 9.60); the effect of Raven level A was low and non-significant (1.01, $p > .5$; odds = .02). Therefore, it seems that mastering deductive reasoning early does contribute to the acquisition of related awareness, which will then contribute to the mastery of higher-level reasoning.

In conclusion, in line with prediction 4ii, cognizance is a powerful factor of transition that varies with developmental phase. However, it may receive influences from reasoning at crucial phases of development, when new reasoning possibilities are mastered. This is in tune with its role to register inferential and representational processes and use the experience for their further development.

4. Discussion

Findings were generally in line with our predictions. In accordance with the first prediction, perceptual awareness and first-order ToM, together with simple inductive and deductive reasoning are acquired at preschool; inferential awareness, awareness of cognitive processes, and relational and deductive reasoning are mastered in late childhood. In line with the second prediction, the various processes preserve their relative functional and organizational autonomy being, at the same time, in interaction with each other. This interaction emerges as a general factor standing for their sharing of common processes and/or constraints and facilitations exchanged between processes. In line with the third prediction, cognizance appeared to stand out as a power proxy of this general factor. However, in line with prediction 4 cognizance is task- and developmentally specific. For instance, it is expressed via perceptual awareness and ToM in preschool and inferential and cognitive awareness in late primary school. This may explain why ToM dominated developmental research and theorizing for two decades. Specifically, its importance in early childhood comes from its role as a good representative of general intellectual processes dominating in this phase (Coyle et al., 2018). This dominance diminishes later in development or in the context of tasks that do not require it per se.

Task- and phase specialization of cognizance may be its raison d' etre: That is, as an evolved competence, it was acquired to allow tuning cognitive functioning with current task demands, given the individual's developmental state and history. This is reflected in the finding, in line with our fifth prediction, that change was constrained by two inversely operating forces. On the one hand, *within a given developmental cycle*, the initial state of ability appeared to impose a ceiling on future attainments; the closer one was to this ceiling the less room was left free for change. On the other hand, there was a general developmental momentum driving change across different mental processes. Those far from the ceiling tend to change fast across the board to reach the ceiling. This momentum reflects interactions between the various processes with cognizance in the lead. It is notable that Tucker-Drob, Bradmaier, and Lindenberger (2019) recently found a general factor for cognitive aging that strengthens with advancing age. This indicates that the general developmental factor may be a universal power operating beyond the age period or processes examined here.

Early in a cycle, cognitive processing contributes experiences to cognizance. In the present study, for instance, mastering (pragmatic) deductive appeared to facilitate changes in cognizance. Later in the cycle, however, awareness of cognitive processes appeared to have a catalytic role in the acquisition of complex inductive reasoning which will open the next developmental cycle. Notably, the differentiation between a factor standing for the state of cognitive processes at a given time and a factor standing for developmental momentum indicates that developmental differences may alter initial individual differences in ability. In other words, development as such operates as a factor transforming the possibilities that appear to dominate at a given time.

The measures of cognizance examined here are, partly, snapshots of reflection that took place in the past. It may then be useful to hypothesize how cognizance may function in different developmental cycles. Early in development, abstractions operate on experiences associated with perception-based action episodes. For instance, paying attention to sounds to recognize and then turning to see where they come from gradually enables the infant to realize that hearing relates to sound, seeing to vision, and that shifting between them generates more inclusive experiences allowing to check each other's accuracy. Episodic awareness of perception-action-object blocks is already present in the second year of life. Capitalizing on them engenders representational awareness at the age of 3–4 years, when children understand that mental states emerge from the senses (our perceptual awareness tasks) and that different people may have different mental states depending on their own perceptual experiences (ToM tasks). This awareness brings mental states in focus of the "mind's eye" allowing to explore their relations. It is no coincidence that at 4–5 years of age children already have some awareness of their ignorance, implying recognition of information missing from their representation of a given situation (Robinson, Rowley, Beck, Carrol, & Apperly, 2006). They also justify wrong-doing or failure by reference to lack of intention for specific actions: "It was a mistake, I didn't want it". Research shows that at 4–5 years, children attribute ignorance and false beliefs to lack of perceptual knowledge and they judge intentions in reference to a person's knowledge state (Joseph & Tager-Flusberg, 2010). Realizing ignorance in concern to a question (e.g., "Where is dad today?") or that an inference was wrong vis-à-vis a given reality (e.g., "I thought my ungle was at home because his car was parked outside, but he was not") turns cognizance to the relations between representations as such. For instance, a question may have several answers; choosing one depends on having specific information. (e.g., "Dad is usually at work but today is a holiday; dad does not go to work on holidays"). A premise may lead to alternative conclusions depending on other premises it is associated to (e.g., "Uncle's car was broken"). Awareness that inference is based on multiple representations that may be connected by alternative relations emerges at the end of the representational cycle as indicated by the effects of inductive reasoning on cognizance. Deductive reasoning as such comes in focus early in the next cycle, indicating that inferential choices themselves become the object of reflection in sake of optimizing conclusions. This generates awareness of inferential control; that is, that the inferential process may take alternative roads depending with what representations are connected and how they are connected. When attained, this awareness may be used to arrange sequences of executive acts, relations in an inductive reasoning tasks, or premises in deductive reasoning tasks. Hence, the highly organized cognitive attainment observed at the end of childhood.

4.1. Implications for developmental, cognitive, and psychometric theories

Classic (Piaget, 2001) and modern theories (Allen & Bickhard, 2018; Zelazo, 2015) of cognitive development did recognize that cognizance is a powerful developmental factor driving the development of general reasoning processes. Research focusing on aspects of cognizance, such as metacognition (e.g., Amsel et al., 2008; Kuhn, 2008; Moshman, 2015; Schneider, 2008) and Theory of Mind (e.g., Perner, 1993; Wellman, 2014; Wimmer et al., 1988) highlighted the development of important processes involved in mental awareness. This study demonstrated the mediating role of cognizance over a crucial period of development vis-à-vis other important mental processes, such as executive control and reasoning. These findings bear important implications for developmental, cognitive, and psychometric theories of the human mind and for brain research.

4.1.1. Developmental theory

For developmental theory, the present findings suggest strongly that mental awareness is always part of cognitive development, participating in the formation of executive control and reasoning in phase appropriate ways. Phenomena that dominated developmental research for decades, such as Theory of Mind, are in fact no more important than other phenomena emerging in other developmental phases, such as inferential and cognitive awareness in late childhood or accurate self-evaluation in adolescence (2018b, Demetriou et al., 2017).

4.1.2. Cognitive theory

In cognitive science, some theories (Koch, 2012) assume that consciousness is important for facing the unexpected by planning based on options one is aware of. Others argue that "consciousness" contains no top-down control processes and has no executive, causal, or controlling relationship with any cognitive processes attributed to it (Oakley & Halligan, 2017). Our findings are in line with the first position. We showed that cognizance mediates between executive and inferential processes, as assumed by some theories (2007, Block, 1995; Dehaene, Lau, & Kouider, 2017). Moreover, we showed that the road from the unconscious to phenomenal consciousness and from there to access consciousness is developmental: attentional/executive experiences first yield perceptual awareness at 4–6 years and this yields inferential awareness, ending up- in self-evaluations and self-representations. Obviously, these findings do not solve the hard problem of consciousness (Chalmers, 2010). They show, however, that resolving the easy problems of consciousness (how humans become increasingly aware of their mind with development) is part of the solution of the difficult problem. These developmental changes alter the very nature of consciousness, i.e., of the "how it feels to be in a given mental state".

4.1.3. Psychometric theory

Awareness is completely ignored by classic theories of intelligence (Carroll, 1993; Hunt, 2011; Jensen, 1998). However, our findings suggest that cognizance is a powerful component of fluid intelligence liaising its two integral components, i.e., executive and inferential processes. This study showed longitudinally that knowing the state of cognizance at Time 1 allows predicting the state of fluid intelligence at Time 2 much more strongly than predicting cognizance from fluid intelligence. Recently, interactive theories of intelligence emerged as an alternative to theories postulating a ubiquitous g factor (Hunt, 2011; Jensen, 1998). According to these theories, commonalities between processes are caused by the dynamics of their interaction as such rather than by any privileged process shared by all other processes (van der Maas et al., 2006; van der Maas, Kan, Marsman, & Stevenson, 2017). Admittedly, interaction may be an important aspect of efficient and coherent mental functioning. However, interactions are not blind in the human mind. They are guided by a factor optimizing choices of mental or behavioral actions. This is cognizance which comes in support of Kant's approach to the mind positing that all cognition must 'be combined in one single self-consciousness". It is time for theories of intelligence to integrate self-awareness into their constructs as a factor of individual differences in intelligence and for intelligence tests to include measures of it in their batteries (Demetriou, Makris et al., 2018; Demetriou & Spanoudis, 2018; Demetriou et al., 2018).

4.1.4. Developmental psychopathology

The present findings bear some important implications for theories about autism. The theory of mind account of autism ascribed the difficulties in socialization and interactions with other persons faced by autistic individuals to their lack of ToM (Baron-Cohen, Leslie, & Frith, 1985). The present study indicates that ToM is an expression of a central cognizance mechanism rather than an autonomous function. Hence one might assume that autistic individuals would also suffer impairment in metacognition and other functions that require sophisticated central control. There is evidence that this is the case. For instance, there is research showing that metacognition is also impaired in autism (Grainger, Williams, & Lind, 2016). Interestingly, there is also research showing that WISC underestimates intelligence in children with autism compared to the Raven Progressive Matrices (RPM) (Nader, Courchesne, Dawson, & Soulieres, 2016). This is to be expected from the point of view of the present model. Specifically, RPM is rather simple from the point of view of executive direction required: it requires to look for relations between the various figures presented in the matrixes all the way through from simple to complex. The WISC is more complicated. It involves various modules addressing very different processes ranging from memory to domain-specific reasoning and handling of meaning at various levels. Thus, it requires more complex executive and meaning-making processes than RPM, justifying lower overall performance than in RPM in individuals with impaired central processing mechanisms. This interpretation would also account for the high performance of autistic individuals on tasks requiring focusing on specific patterns of information, such as spotting a picture embedded in a complex whole or identifying and recalling recurrent patterns of numerical information. These tasks require recurrent application of a well-focused scheme of action without a need for a flexible adaptation to changing needs and integration over different processes. This assumption is in line with the central coherence account of autism proposed by Frith and Happe´ (1994). Central coherence refers to the disposition to look for relations and reduce to an underlying theme or gist across characteristics and specific aspects of information in a task. According to this hypothesis, the disposition for central coherence is impaired in autism. In the terms of the present paper, cognizance may be the general coherence mechanism that is impaired in autism. Obviously, this is a question to be examined by future research.

4.1.5. Brain research

Brain research provided evidence in agreement with the present finding about a common awareness core associated special functions allowing cognitive self-awareness (metacognition) and awareness about the others' minds (ToM). Specifically, there seems to be a specific mentalizing network in the brain associated with awareness of mental states of oneself and the other. ToM correlates with activation of the right and left temporo-parietal junction, medial parietal cortex (including posterior cingulate and precuneus), medial prefrontal cortex, and STS/MTG (Frith & Frith, 2003; Siegal & Varley, 2002). Self-representation correlates with medial prefrontal cortex, posterior cingulate cortex, and superior temporal cortex bilaterally (Vogeley et al., 2004). Therefore, medial prefrontal cortex and posterior cingulate are, minimally, part of the networks associated with understanding one's own and other's mental states. These networks interact with attentional networks, activating ventral and dorsal attentional systems when processing one's own and others' mental states (Abu-Akel & Shamay-Tsoory, 2011; Mahy, Moses, & Pfeifer, 2014) and overlaps with networks associated with analogical and deductive reasoning, such as the IPL-rlPFC network and the DLPFC and the VLPFC network (Wendelken, Ferrer, Whitaker, & Bunge, 2015). Noticeably, meta-cognitive reflection training resulted into improvements in executive function and theory of mind. Most importantly, this training resulted into changes in brain function itself, reducing the amplitude of the N2 component of the ERP, which indexes conflict detection (Espinet, Anderson, & Zelazo, 2013). It seems that the mediation of cognizance between executive and inferential processes has its brain analogue in a hierarchy of neural networks generating awareness which integrate different aspects of action, cognitive or behavioral into a sequence of components one is aware of. Obviously, this network systems are reminiscent of cognitive systems mapped by this study. Future research would have to explore how rewiring, differentiation, and re-integration of network hierarchies in the brain results into increasingly more accurate selfmappings and ensuing flexible representational choices, according to mental and behavioral goals.

4.2. Limitations

A major limitation of this study and any study exploring the development of representations and awareness about them comes from the lack of control over the representational experiences of children. In the present study, for instance, children receive massive training in dealing with representations throughout the age period covered. Learning to read and write and arithmetic, starting at preschool and culminating in early primary school, enables children to acquire new representations and learn how to integrate them into systems of increasing complexity. Probably less systematically, children are taught strategies to by-pass cognitive limits, such as strategies for storing, recalling, and using representations in sake of learning new ones. Learning in different domains, such as the natural and the social world, causes conceptual change as old concepts are integrated with new ones, modified, or abandoned. Many of the age and individual differences observed here may reflect these experiences to a large extent rather than just spontaneous developmental processes. Moreover, they may reflect random factors, such as differences between teachers, schools, or the family environment of individual children. Therefore, one ought to be aware of the possibility that the patterns observed may be contaminated by uncontrolled factors to a considerable extent. Obviously, the longitudinal nature of the study compensates for this weakness to some extent. Ideally, however, many more testing waves and larger more diversified samples would be needed to disentangle systematic developmental forces from more random forces. Hopefully, this study was a first step in the formation of hypotheses to be tested more systematically by future research.

4.3. Conclusions

To conclude, this study strongly suggested that there is a central core of cognizance underlying awareness of one's own and others' mental states. Special forms of awareness, such as metacognition and ToM, reflect implementations of this core in different aspects of the mind. This core develops systematically through the years, emerging from cognitive actions or experiences and contributing to their further development, in an ever-changing spiral of interactions with executive and reasoning process. As a result, cognizance mediation is phase-specific, each time bearing the dominant representational characteristics of the phase concerned. Practically, this state of affairs renders cognizance an important part of intellectual competence; individual differences in cognizance at any developmental phase may explain individual differences in processes traditionally associated with intelligence, such as reasoning. In development, change obeys its own dynamics which bind change in executive, awareness, and reasoning processes together, often overwriting the state of ability at a specific point in time. Future research would have to explicitly manipulate each process to specify how it affects the rest, from birth to maturity, if not over the life span.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cogdev.2019.100805.

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